Naval Submarine Medical Research Laboratory

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Underwater and Dive Station Work-Site Noise Surveys

by

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Previous work performed by the Naval Submarine Medical Research Laboratory (NSMRL) has developed in-water permissible continuous noise exposure guidance. And the Navy Experimental Diving Unit (NEDU) has measured in-water noise levels produced by in-water tools and developed permissible exposure levels based upon applying in-air guidance and temporary threshold shift (TTS) data. This study extends these previous works by obtaining in-water and in-air noise measurements and a total noise dose for Navy divers during actual diving operations using a portable sound level meter system capable of both in-water and in-air measurements. Noise measurements were used to calculate Noise Permissible Exposure Levels and doses for both helmeted and SCUBA divers and results of both in-water and in-air measurements were compared to existing guidance.

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ABSTRACT

BACKGROUND: Previous work performed by the Naval Submarine Medical Research Laboratory (NSMRL) had developed in-water permissible continuous noise exposure guidance. Work performed by the Navy Experimental Diving Unit (NEDU) measuring in-water noise levels produced by in-water tools to develop permissible exposure levels based upon applying in-air guidance and temporary threshold shift (TTS) data. This study extends this previous work by obtaining in-water and in-air noise measurements and a total noise dose for Navy divers during actual diving operations using a portable sound level meter system capable of both in-water and in-air measurements. Noise measurements were used to calculate Navy Occupational Exposure Limits (NOEL) and doses for both helmeted and Self-Contained Underwater Breathing Apparatus (SCUBA) divers. The results of both in-water and in-air measurements were used to calculate total noise dose and these dosages were compared to existing guidance.

METHODS: After giving a presentation and attending meetings with fleet Master Divers and Diving Officers at the 2002 Navy Working Divers Conference, commands volunteered to participate in this project. Data were collected using the portable sound level meter system during five sets of diving operations: salvage (1), ship's husbandry (1), underwater construction (2), test and evaluation (1), and research (1). In addition to calculating NOELs and Total Noise Dosages to compare to guidance, on-site permissible exposure levels were calculated for two non-Navy approved tools during diving operations so hearing loss mitigation could be incorporated immediately during diving operations. The majority of the measurements were performed on divers using the MK-21 diving helmet, which involves in-air exposure for the helmeted diver and the application of in-air guidance. Two of the six data collections involved in-water noise exposure for SCUBA divers; in these instances NSMRL in-water guidance was applied. In-water and in-air noise measurements for this study were collected between July 2002 and November 2003.

RESULTS: In-water measurements were obtained for several tools/equipment both in water and in air during diving operations. The results showed that in some instances in-water noise dose was substantially higher than in-air dose for the work-shift, whereas in other instances both in-water and in-air noise doses were high and both of these scenarios placed the diver at risk for hearing loss. There were also instances where in-water noise dose was negligible and in-air dose was very high. Valid and reliable NOEL and Total Noise Doses were calculated for several different types of diving operations and in two instances (one salvage, one ship's husbandry) on-site, in-water permissible exposure limits were provided to Diving Supervisors for non-Navy tested tools to be used during the diving operations. Divers from two different dive lockers were trained to perform measurements independently using the portable sound level meter system to demonstrate that working divers could perform valid and reliable measurements using the same procedures carried out by research personnel.

CONCLUSIONS: A valid and reliable procedure that Navy divers can be trained to perform has been established to measure and sum in-water and in-air noise levels to obtain a total noise dose, and these measurements can be easily compared to existing in-water and in-air guidance. The results indicate that Navy divers are potentially at risk for suffering noise-induced hearing loss from in-water and in-air exposure, both individually and in combination during existing diving

operations. In air, topside noise exposures can be mitigated substantially by the use of hearing protection. Previous work has also established that the MK-21 diving helmet does provide effective sound attenuation in the water, particularly in the high frequency range of human hearing.

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SUMMARY

THE PROBLEM

The Navy diver performs a diverse array of job functions (e.g., ship cleaning/repair, underwater construction) that involve working in a background of noise from a variety of sources, both in and out of the water. Research has indicated that 18 to 29% of Navy personnel show a significant hearing threshold shift on annual hearing conservation audiograms (Wolgemuth, Luttrell, Kamhi, and Wark 1995; Bohnker, Page, Rovig, Betts, and Sack, 2004; Bealer, Wolgemuth, Rovig, and Page, 2005). A study of U.S. Navy divers showed that over 70% of divers showed at least one significant hearing threshold shift after 20 years of service (Cudahy & Avila, 1998). Parvin and Cudahy (2003) published underwater noise guidance that applies to the US Navy and UK. It was noted that proper application of the guidance would require in-water noise monitoring capability. Noise monitoring should be required under those scenarios that have potential for exceeding noise-exposure criteria using an established, valid, and reliable procedure that is easy to use to provide maximum protection to the diver.

METHOD

Recent developments in the miniaturization of sound measurement instrumentation and sensors have made possible a portable underwater sound level meter system suitable for use by topside personnel. The Underwater Sound Level Meter (USLM) system had been successfully used to measure sound levels both in water and in air in laboratory and controlled field settings. The USLM system consists of a hand-held unit connected to a hydrophone on a 100-meter cable. The hand-held USLM system collects and stores the data and has some analysis capability. There is also an in-air microphone that can easily be switched out (within 5 minutes or less) with the hydrophone to the same hand-held unit for in-air measurements. The USLM system was used to take measurements at dive sites both under water and in air.

FINDINGS

Methods and procedures were developed to perform valid in-water and in-air noise measurements using a portable sound level meter system capable of making both types of measurements during five sets of Navy and one set of National Oceanic and Atmospheric Administration (NOAA) diving operations. The measurement results were used to calculate Navy occupational exposure limits and noise dosages for both in-water and in-air environments for Navy and NOAA divers. In-water measurements were made by attaching a hydrophone to either the diver's helmet (MK-21) or tool line, or by having a Self-Contained Underwater Breathing Apparatus (SCUBA) diver hold the hydrophone base. All in-water measurements using the USLM were made locating the hydrophone near the noise source and with a hydrophone cable running to the surface where noise measurements were read and recorded by research staff. The Total Noise Dose (in-water plus in-air noise doses) was then calculated for the divers during a 24-hour period. During two of the data collections, on-site NOELs were calculated for non-Navy approved in-water tools (20K psi hydroblaster (Not a trade name.), hydraulic drill press) during diving operations to mitigate potential hearing damage to the divers. Two separate dive teams were trained to use the portable, USLM system and did so successfully

to obtain valid and reliable in-water noise level data. In-water and topside in-air noise measurements can be successfully obtained during actual diving operations and the data can be used to calculate permissible exposure times and total noise doses for the divers to be compared to existing in-water and in-air guidance.

INTRODUCTION

Background

The Navy diver performs a diverse array of job functions (e.g., ship cleaning/repair, underwater construction, salvage) that involve working in a background of noise from a variety of sources, both in and out of the water. Recent data indicate that 18 to 29% of Navy personnel show a significant hearing threshold shift on annual hearing conservation audiograms (Wolgemuth, Luttrell, Kamhi, and Wark 1995; Bohnker, Page, Rovig, Betts, and Sack, 2004; Bealer, Wolgemuth, Rovig, and Page, 2005). A study of U.S. Navy divers (Cudahy & Avila, 1998) showed an overall significant threshold shift (STS) rate of 41%, higher than for the general Navy population. Cudahy and Avila (1998) also found the pattern of hearing loss for career Navy divers to be typical of that for noise-induced hearing loss in air (i.e., moderate high-frequency hearing loss). The results of these studies demonstrate a clear need to protect diver hearing, and the U.S. Navy has recognized this by incorporating the Navy Submarine Medical Research Laboratory (NSMRL) product, "Safe Diving Distances from Transmitting Sonars" instruction into the U.S. Navy Diving Manual (U.S. Navy Diving Manual, Rev 5, Change A, 2000). Parvin and Cudahy (2003) have published a summary of guidances applying to diving personnel. In-air hearing guidance for all Navy noise-exposed personnel, including divers working on the surface, is provided by the Navy Occupational Health and Safety Instruction for ashore commands (OPNAVINST 5100.23G, Chapter 18, 2005).

Research into the impact of underwater noise on divers has also introduced the issue of protecting the diver from both auditory and non-auditory effects of intense sound. It has become apparent that sound affects not only the auditory system, but physiological systems associated with air-filled spaces such as the lungs, sinuses, stomach, and intestines (Cudahy, et al, 1999). These effects occur because water and the body have very similar physical characteristics and acoustic energy can pass easily from water through the body and into internal organs.

During a presentation by NSMRL staff concerning new underwater noise guidance to the Navy Bureau of Medicine and Surgery (BUMED) in 2001, it was noted that proper application of the guidance would require in-water noise monitoring capability. To provide maximum protection to the diver under different scenarios that have potential for exceeding noise-exposure guidance criteria, monitoring should be performed under those scenarios using an established, valid, and reliable procedure that is easy to use. Previous studies that examined the relationship between underwater tool noise measurements and existing in-water noise guidance have been rare (Smith, 1984). There have been studies performed examining the relationship between tool noise and temporary threshold shift (TTS), but they were limited in scope and all used different measurement procedures with non-portable equipment.

The Effects of In-Water Tool Noise on Hearing

Mittleman (1976) and Sterba (1987a) both examined the impact of in-water impulse noise on SCUBA divers. In both studies, divers were exposed to impulse noise-producing stud guns, gun-powdered tools that force threaded fasteners into steel plates for ship and submarine repairs. In-water noise measurements typically are referenced to 1µPascal (Pa), however, in both of these studies the in-water levels were referenced to the in-air reference of 20µPa (values referenced to

20μPa are 26 dB less than values referenced to 1μPa). In this paper, all noise levels will be referenced to 1μ Pa unless another reference is specified. Sterba (1987a) reported that up to 40 shots with the Ramset HD 200 stud gun with an average peak sound pressure level (peak SPL) of 211.4 dB at a depth of 19 feet of sea water (fsw), did not produce STS in Navy SCUBA divers[1]. The reason given for divers ceasing tool use after 40 shots was due to hand, rather than hearing, discomfort. Mittleman (1976) measured in-water SPLs for three different stud gun models, including the Ramset HD 200. At distances of three and six feet from the diver's head or chest, peak SPLs ranged from 211 to 221.3 dB. Mittleman did not report audiometric test results; however, he reported there were no adverse or noticeable effects on diver ears, lungs, or sinuses after firing 76 shots from the stud guns at 10 fsw. Mittleman (1976) proposed that due to the air-water impedance mismatch, which results in in-water auditory thresholds being elevated approximately 55 dB above in-air thresholds, the in-air impulse noise damage risk level of 140 dB re 20μPa could be elevated to a maximum safe exposure level of 221 dB re 1μPa in water for brief and occasional exposures. Both of these studies used hydrophones connected to large, reel-to-reel tape recording, non-portable systems to record in-water noise levels. These studies, although valuable, were limited in scope regarding the number of different underwater tools measured and were performed in the same acoustical test pool (20 ft or 6.1m deep freshwater pond), not in an open-water environment. For a description of this test pool, see Gahs and Myers (1995). It is also important to note that the subjects in these projects were SCUBA divers who were directly exposed to noise levels in water as opposed to helmeted divers who receive secondary exposure in air from in-water power tools. In-water noise guidance is very different for SCUBA or MK 20 (full diving face mask) divers than for MK-21 helmeted divers, and this issue is discussed at length in a later section of this report.

Russell and Cilento (1995) and Gahs and Myers (1995) performed related studies that examined in-water and in-air (within the MK-21 diving helmet) continuous noise levels produced by the Butterworth 10K pounds per square inch (psi) thrust gun or hydroblaster operating at 8K psi. The hydroblaster is used for hull cleaning and to cut through Monitor-age metal and lumber during salvage operations with the preferred diving mode being the MK-21 helmet system. The goal of these studies was to determine maximum safe exposure levels when using this particular underwater tool that divers had reported as generating high noise levels. Unmanned and manned data were collected from hydrophones both 10 feet away from the noise source and at the helmet or diver's "right ear." In-water and in-helmet noise levels were measured in addition to TTS assessment in MK-21 suited divers using the Hydroblaster (Russell & Cilento 1995). Unmanned testing involved mounting a MK-21 helmet on a Brüel and Kjaer (B&K) head simulator (type 4128) with the hydroblaster mounted at the "right ear" of the helmet. All in-water and in-helmet data were routed to frequency and spectrum analyzers (non-portable) on the surface.

All measurements were performed in the same acoustical test pool used by Sterba (1987a) and Mittleman (1976), at a depth of 10 fsw (3.1m), for both the standard hydroblaster setup and with a 12 inch counter-thrust extension or "silencer" attached to the tool. As in previous studies, in-water noise levels were converted to dB re 20μPa. Russell and Cilento (1994) also then applied dB (A) scale correction factors, the mean MK-21 diving helmet acoustic transfer function (sound attenuation) correction factors, and power summed one-third-octave and levels to obtain a single

[1] At the time these studies were performed, Department of Defense STS was defined as either a ±10 dB average difference at 2, 3, and 4 kHz, either ear, or a ±15 dB difference at the individual test frequencies of 1, 2, 3, or 4 kHz, either ear.

number dB (A) level. This level was then used to calculate an in-air, within the helmet [2]NOEL per OPNAVINST 5100.23E using the following formula:

$$\frac{16}{2^{(L-80)/4}}$$

L = Measured dB (A) level

Both unmanned and manned noise levels and human diver TTS data confirmed that using the *silenced* hydroblaster would allow a noise occupational exposure level (NOEL) of up to 85 minutes in water, based on Navy occupational exposure guidelines (Russell & Cilento, 1995; Gahs & Myers, 1995).

Knafelc (1997) measured in-water noise levels, both unmanned and manned, for divers in MK-21 and MK-20 dress for three hydraulic tools: a **needle descaler** (Fairmount Hydraulics Model HU4805)**,** a **grinder** (Stanley Model GR24301), and a heavy-duty **impact hammer** (Stanley Model IW20360). The purpose of this study was to make recommendations for noise exposure limits when using these tools in the water. Measurements were performed in the same acoustic test pool used by Sterba (1987a) and Mittleman (1976). Knafelc (1997) applied the dB re 20µPa and (A) weighted conversions and MK-21 acoustic transfer correction factors using the same techniques as Russell and Cilento (1995) to develop in-air, in-helmet NOELs. Divers also underwent pre- and post-in-water noise exposure audiograms on the surface. NOELs for MK 20 divers were estimated based on overall in-water dB SPL (unweighted re 20µPa over the frequency range of 25-20,000 Hz) and using BUMED interim guidance developed by Smith (1984). Post-exposure audiograms, unlike other in-water TTS studies, were typically performed within two minutes after completing a dive so TTS_2 (Amount of TTS observed two minutes post-exposure.) was determined. NOELs for the needle descaler were 30 and 42 minutes, respectively, for the MK-20 and MK-21 dive rigs. For the grinder, NOELs were 202 and 30 minutes and for the impact hammer, 40 and 85 minutes, respectively, for the MK 20 and MK-21 dive rigs. Knafelc (1997) concluded the following: 1) in-water noise levels varied during a dive as the diver moved into different positions and locations relative to the noise source and 2) unmanned estimates of NOELs were larger and, thus, underestimated risk of TTS as compared to NOELs based on manned testing. The reported NOELs for both diving rigs were recommended as conservative, interim guidance for these particular tools until further data based on more complete in-water noise guidance was obtained.

Molvaer and Gjestland (1981) measured in-air noise levels during in-water exposure for two types of diving helmets, the Siebe-Gorman and the Kirby Superlite 17 (similar to the Navy's MK-21), for noise produced by a pneumatic rock drill and a high-pressure waterjet lance. These tools are used for underwater construction and cleaning jobs, respectively. In-water noise measurements for these tools were also made for SCUBA (non-helmeted) divers. All measurements were made in an open-water environment at a depth of 25 fsw (7.8m). Waterjet lance noise levels ranged from 136 to 170 dB and the pneumatic rock drill 120 to 153 dB re 1µPa. Open-water ambient noise levels were also measured and ranged from 111 to 136 dB re

[2] Currently, the Department of Defense defines STS as an average shift or difference of $\pm$ 10dB for 2, 3, and 4 kHz.

1μPa to help place in-water tool noise levels into proper environmental context since the undersea environment is not a silent one.

Molvaer and Gjestland (1981) used correction factors to convert in-water noise levels to dB (A) levels within the helmet the diver would be exposed to in a manner similar to Russell and Cilento (1995). For the SCUBA diver exposures, the recommended damage risk level was adjusted to represent the difference between in-air and in-water hearing thresholds (impedance mismatch, 55 dB) in a manner similar to Mittleman's (1976) recommendation. Diver TTS data in this study, for both helmeted and SCUBA divers, indicated that in-water noise exposure greater than one hour using these tools might be hazardous to diver hearing.

These studies made valuable contributions to the understanding of in-water noise exposure effects for specific tools and in-water conditions. However, these data have several limitations. At the time of these investigations, there was no comprehensive, empirically based in-water noise guidance for bareheaded, hooded, or helmeted divers. Most of these data were collected on helmeted divers where noise exposure was in-air; therefore, in-water levels were converted to dB (A) in-helmet levels and applied to either existing interim in-water guidance or to in-air noise damage risk criteria. The TTS data associated with in-water tool noise was typically performed 10 to 25 minutes after the exposure (Molvaer & Gjestland, 1981; Russell & Cilento, 1995), long after the occurrence of maximum TTS (Lipscomb, 1994). The TTS measures, although valuable, did involve potential risk for divers incurring permanent hearing damage. Another issue is that except for Molvaer and Gjestland (1981), there has been a lack of in-water exposure data collected during open-water diving operations.

Since the last of these studies were completed, additional underwater psychoacoustic research performed at NSMRL determined that BUMED interim in-water noise guidance (Smith, 1984), based on impedance mismatch (Mittleman, 1976) and sensory magnitude (Smith, 1984) theories were incorrect in assuming the dynamic range for hearing in water was equal to that of in air. Smith and Wojtowicz (1985) demonstrated that using a fixed difference between air and water thresholds could not be used to estimate TTS. Recent human data collected at NSMRL and animal work performed by NSMRL collaborators has led to development of new in-water noise guidance without using high-risk TTS measures (Cudahy, 2002). Technological advances and adaptations have also made it possible to perform topside measurements of in-water noise levels using portable, easy to operate equipment. NSMRL developed, with support from the Naval Sea Systems Command (NAVSEA) and by using parts developed by the Brüel & Kjaer Corporation, a topside system (electronics in a dry surface area connected by underwater cable to a hydrophone located near the diver) to measure underwater sound levels within specific areas. Means now existed to fill a knowledge gap between in-water noise levels for potential, current Navy high noise diving scenarios and current noise guidance. In addition, a study that assessed both in-water and in-air total noise exposure and dose for a diver over a 24-hour period during diving operations had not been performed.

Based on the limitations of prior studies and the technology now available, it was decided a current in-water and topside, in-air data collection effort with accompanying standardized noise measurement procedures were critical components in the development of a Navy diver hearing-conservation program. There were three goals for this project. The first was to develop and use a valid and reliable, established procedure to collect and compile in-water and in-air noise data for dive work sites, i.e., noise survey sample for several types of in-water tools and in-air diving support surface equipment, during actual diving operations. The second was the development of procedures that would form the basis for the diver noise monitoring and mitigation program, including on-site NOEL and noise dose calculations. From these two tasks, the third goal was to identify key training elements that would serve as input to the Navy Diving and Salvage Training Center's (NDSTC) for development of a noise measurement-training curriculum for dive personnel.

METHODS AND PROCEDURES

Subjects

This project involved making in-water and in-air noise measurements during actual Navy diving operations and was not an experimental research design; thus, the NSMRL Institutional Review Board (IRB) determined that divers involved in this study were not research subjects. All participants in the diving portions of this project were certified U.S. Navy or U.S. Army military divers, U.S. Navy civil service divers, or National Oceanic and Atmospheric Administration (NOAA) divers.

Participating Dive Commands

Diving and surface data collections were accomplished by working with the following commands: Public Works Center Divers, Naval Station San Diego, CA; Mobile Diving and Salvage Unit Two, Naval Amphibious Base, Little Creek, VA; Mobile Diving and Salvage Unit One, Naval Station Pearl Harbor, HI; Naval Diving and Salvage Training Center, Panama City, FL; and the National Atmospheric and Oceanic Administration/University of North Carolina-Wilmington Aquarius Undersea Habitat, Key Largo, FL. The actual dive locations and profiles will be discussed in the Results section of this report.

Noise Measurements and Procedures

Recent developments in the miniaturization of sound measurement instrumentation and sensors have made possible the development of a portable underwater sound level meter system (USLM) suitable for use by topside personnel. The Underwater Sound Level Meter had been successfully used by NSMRL to measure sound levels both in water and in air in laboratory and controlled field settings. Two B&K hand-held units were used in this study, the 2236 and 2238 systems. Both USLMs consisted of a hand-held unit connected to a hydrophone (underwater sound sensor or microphone) on a 100-foot cable (Figure 1). For one data collection series a hydrophone cable longer than 100 feet was required to perform in-water noise measurements at a depth of 230 fsw. In this instance, different cables were spliced together using Scotchguard kits to create a 450-foot cable. The respective hand-held USLM units collected and stored the data and had some analysis capability. The B&K 2238 sound level meter system also had noise dosimetry capability.
The majority of the in-water measurements were performed with MK-21 helmeted-divers using tools, and the hydrophone cable was typically attached to the diver's umbilical line, with the

hydrophone itself attached to the handle of the MK-21 helmet. The hydrophone cable was attached to the umbilical line using either chemical tape (waterproof) or zip ties. Two of the data collection series involved in-water noise exposure for SCUBA divers. In both of these instances, one of the divers held the hydrophone base in his hand in a manner such that the sensor area was not touched. The hydrophone cable was free-floating for these measurements because the divers did not have umbilical or tending lines. All underwater noise measurements for both helmeted and SCUBA modes were displayed on the USLM's digital display screen and were recorded by topside personnel on data sheets.

Most of the helmeted dives were performed at depths ranging from 7 to 40 fsw, with the one exception being dives to 230 fsw on a salvage job. For the 230 fsw measurements, the nature of the diving operations made it necessary to attach the hydrophone cable to the hydraulic tool line connected to the tool itself rather than to the diver's umbilical and helmet. The hydrophone in this instance was free-floating approximately three to six feet from the tool itself. Noise measurements involving SCUBA divers were conducted at depths of 10 to 50 fsw.

The cable adapter that connected the cable and hydrophone to the USLM system could be easily removed and a microphone that attached to the hand-held unit for in-air measurements could be installed in less than two minutes. Appendix A is a *Quick Setup* Operating Procedures manual. Appendix B is a comprehensive, detailed USLM System Operating Procedures Manual that includes photographs and descriptions of the working parts and adapters and how to set up the equipment for both in-water and in-air measurements. Appendix C is a data sheet for recording in-water and in-air sound measurements, respectively. Figure 1 displays the components of the portable in-water and in-air sound measurement system, Figure 2 shows a close-up view of the hydrophone attached to the MK-21 diving helmet, and Figure 3 shows a diver with the hydrophone and protective case attached on the surface after completion of diving operations.

Figure 1. Underwater and Topside Sound Level Meter System in carrying case. Photograph taken by Mr. Derek Schwaller, NSMRL Biomedical Engineer.

Noise Dose Calculations

For this project the USLM made measurements both in-water and in-air so a total "noise dose" over the length of the dive operation work-shift could be calculated. **Noise dose** was calculated by taking the ***Observed Daily Noise Dose*** **(ODND)** in minutes and dividing it by the **Navy Occupational Exposure Limit (NOEL)** in minutes (Gasaway, 1985). NOEL was calculated using the following formula (Russell & Cilento 1995):

$$T = \frac{16}{2(L - 80)/4}$$

L = Noise level measured or calculated in dB (A)
T = Time allowed (in hours)

For helmeted divers, whose in-water noise exposure became in-air exposure as sound transferred through the MK-21 diving helmet, in-air NOELs based on the 4 dB trading rule currently used for the Navy's Hearing Conservation Program (OPNAVINST 5100.23G, 1999) were used to calculate noise-exposure risk. Using these procedures, an individual can be *safely* exposed to an NOEL of 84 dB (A) for an eight-hour period, which is a 100% noise dose. Noise doses that exceed 100% will potentially cause hearing damage (Gasaway, 1985). For every 4 dB increase or decrease in level, the NOEL will be halved or doubled accordingly, and increase or decrease the noise dose.

For helmeted divers, in-water noise levels that are typically referenced to 1µ(Pa) were converted to 20µPa referenced levels used for in-air noise measurements. Next, levels were converted to dB (A) levels using correction factors used for NOEL determinations in air. (The dB (A) scale simulates the auditory weighting function of human hearing.) Next MK-21 helmet mean acoustic transfer factors were applied (Russell & Cilento, 1995) to determine in-helmet, in-air levels and NOELS. For SCUBA divers, NOELs were calculated using correction factors and guidance developed by NSMRL that take into account direct in-water noise exposure (Cudahy, 2002). Topside noise measurements were also performed on and near dive station for equipment used to support diving operations. NOELs for in-air exposures were calculated using the same formula as for in-water measures, although the measurements were made directly in dB (A) levels and MK-21 attenuation levels did not have to be applied. **Total Noise Dose** was calculated by adding **Total In-water Noise Dose (%)** and **Total In-air Noise Dose (%).** The goal was to make determinations if the in-water or in-air noise doses alone, or in combination, were sufficient to exceed the daily allowable dosage (100%) for a Navy diver during a work-shift.

Figure 2. MK-21 Diving Helmet with hydrophone attached to bronze handle on top of helmet, within orange protective case. An enlarged view of the protective case and hydrophone is also provided. Photograph taken by HM2 Steve Conver, USN, NSMRL Otolaryngology Technician.

Figure 3. MDV Rick Donlon, USN(RET) in MK-21 dress exiting the water after a dive that obtained in-water noise measurements. The orange protective case housing the hydrophone can be seen attached to the dive helmet's handle. A portion of the USS ARIZONA Memorial Barge can be seen in the background. Photo taken by BMC(DV) Brian Kerr, USN, NSMRL Saturation Diver.

RESULTS

Former USS MONITOR Gun Turret Recovery Salvage Project

At the request of the Supervisor of Navy Diving, noise measurements were performed as part of this study during the NOAA and US Navy joint project to recover the gun turret of the *Monitor* Civil War ironclad vessel in July 2002. Working with Mobile Diving and Salvage Unit 2 (MDSU-2) and the Navy Experimental Diving Unit (NEDU), NSMRL staff scientists and divers attached a 450-foot hydrophone cable to the hydraulic tool line of a Butterworth 20K psi hydroblaster. Although a less powerful hydroblaster tool made by the same manufacturer (Russell & Cilento 1995) was approved for Navy use (ANU), the 20K psi model was not approved at the time of this study. A hydroblaster is a tool that moves water through a small diameter nozzle under extremely high pressure and is used for ship/submarine hull cleaning and the cutting of heavy objects. For this diving operation, the 20K psi hydroblaster was used under water to cut through the *Monitors'* armor belt (consisting of iron and heavy lumber) so the gun turret could be extracted from under the hull of this sunken ship. (The ship laid upside-down on the sea bottom.) The dive site for this project was accessed from a salvage barge located approximately 18 miles off the coast of Cape Hatteras, North Carolina, and was at a depth of 230 fsw. Divers were in MK-21 dress with boots and hot water suits and were lowered to the dive site via a stage.

At 230 fsw, with the diver and hydroblaster in position on dive site ready to begin work, ambient in-water noise levels were 133 dB linear (L). With the hydrophone attached to the hydroblaster hydraulic tool line and located approximately three to six feet from the hydroblaster nozzle, a broadband level of 196.3 dB (L) was obtained. Octave band levels (1/1) were obtained and Table 1 shows these levels in dB re 1µ Pa and 20µ Pa, dB (A) correction factors, dB (A) levels, and mean MK-21diving helmet sound attenuation levels (Russell & Cilento, 1995). Table 1 also shows the overall (power sum), in-helmet dB (A) level for octave band levels from 125-8 kHz, and the NOEL for the Butterworth 20K psi hydroblaster tool. Figure 4 shows a U.S. Navy saturation diver using the hydroblaster during the *Monitors'* gun turret salvage effort.

Table 1. In-water to in-helmet conversion of dB (A) octave band noise measurements, dB (A) correction factors, dB (A) octave band levels, MK-21 diving helmet attenuation correction factors, octave band dB (A) in-helmet levels, overall in-helmet dB (A) level, and NOEL for the Butterworth 20K psi hydroblaster tool.

Hz	125	250	500	1k	2k	4k	8k
dB re 1µ Pa	147.0	155.8	157.6	167.0	177.0	176.4	177.0
dB re 20µ Pa	121.0	129.8	131.6	141.0	151.0	150.4	151.0
dB (A) Correction Factors	-16.1	-8.6	-3.2	0	+1.2	+1.0	-1.1
dB (A)	104.9	121.2	128.4	141.0	152.2	151.4	149.9
MK-21 Mean Attenuation Correction Factors	-25	-34	-35	-52	-59	-62	-79
MK-21 In-helmet dB (A)	79.9	87.2	93.4	89.0	93.2	89.4	70.9

Overall In-helmet dB (A) Level: 98
NOEL: 42.5 minutes

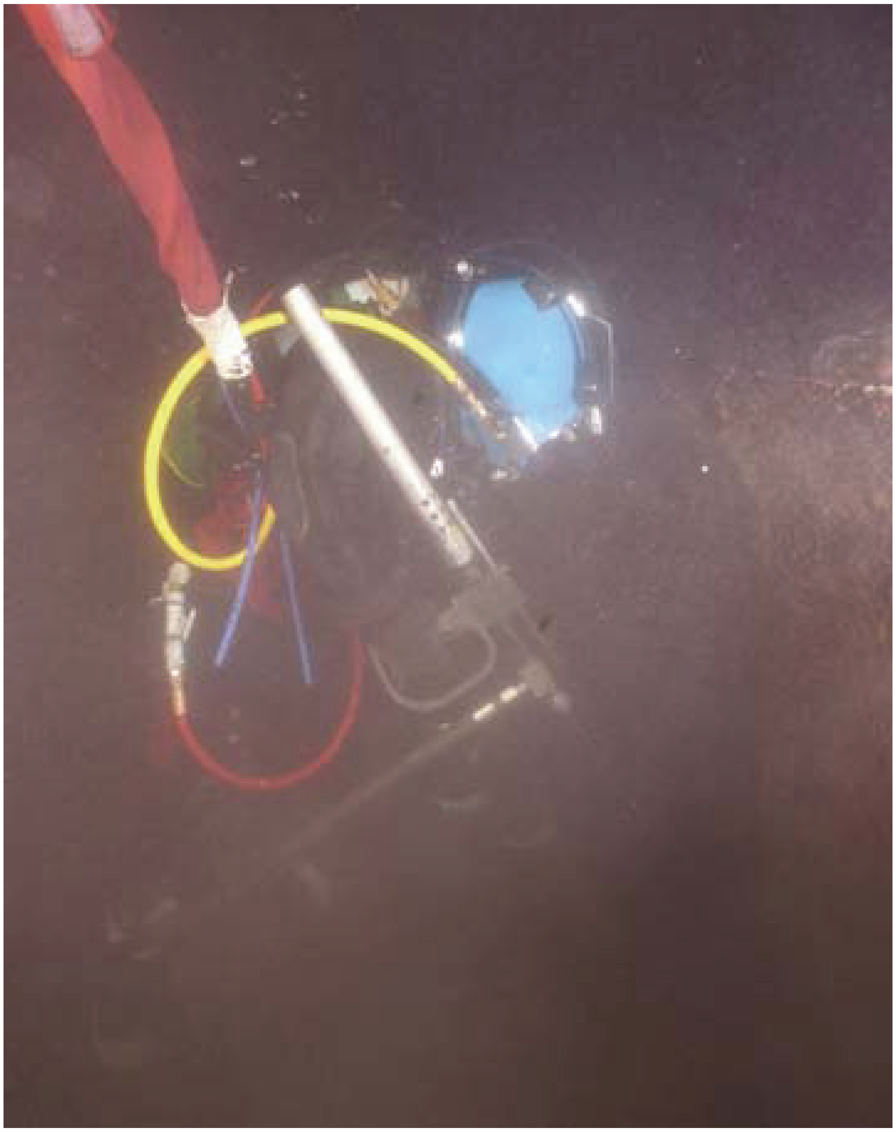

Figure 4. A U.S. Navy Saturation Diver of the Navy Experimental Diving Unit shown using the Butterworth 20K psi Hydroblaster working on the USS MONITOR. Photo taken by underwater photographers assigned to Underwater Combat Camera, Norfolk, VA.

Figure 5. WOTAN salvage barge used by MDSU-2, NOAA, and participating dive commands for the USS MONITOR gun turret recovery project. Note the number of metal structures and two cranes resulting in highly reverberant acoustical environment topside.

The overall MK-21 in-helmet level while using the hydroblaster was 98 dB (A) re 20µ Pa, which results in an NOEL of 42.5 minutes. MDSU-2 was already using a 45-minute maximum time limit for hydroblaster use with a 50% duty cycle (5 minutes on-5 minutes off for a 45-minute period). The recommendation to continue using the existing schedule in lieu of the measured NOEL on-site was a conservative approach that benefited the diver, since allowing exposure up to the maximum of the NOEL can produce TTS in some individuals. Using the 50% duty cycle, a diver would be exposed to 98 dB (A) for 25 minutes during the 45-minute period of allowable exposure, resulting in a noise dose of 56% in-water.

The *Monitor* diving operations were conducted from a salvage barge that was approximately the size of a football field. There were numerous modular structures, steel beams, two large cranes, saturation diving chambers, and other metallic structures that resulted in a highly reverberant acoustic environment (Figure 5). Table 2 displays topside, in-air noise measurements on the barge. A review of the dB (A) levels in air re 20µ Pa for the hydroblaster compressor at distances ranging from 1 to 15 feet shows that the Inverse Square Law in this reverberant working environment does not apply. At 15 feet from the noise source (compressor), there was only a 2.5 dB reduction in noise level (99.9 to 97.4 dB re 20µ Pa, dB (A) scale), whereas the inverse square law would predict a decrease of approximately 6 dB SPL for every doubling of distance. The highly reverberant environment invalidated the inverse square law on the salvage barge. The hydroblaster compressor was operated for 45-minute periods several times (e.g., eight) per day. The outside gym on the barge used frequently by off-duty divers was 10feet from the compressor, resulting in individuals being exposed to 99.4 dB (A) (NOEL = 33 minutes, in the absence of using hearing protection) for the 25 minutes (50% duty cycle) the topside compressor was in operation. This resulted in a 55.5% noise dose for divers working out during compressor operation.

It can also be seen in Table 2 that noise levels in other work and rest areas on the barge ranged from 83 to 99 dB (A) re 20µ Pa when launching and recovering the saturation diving bell, working near the saturation diving chamber compressor or the surface-supplied diving 5000 psi compressor, or operating the crane winch on the surface-supplied dive station. When refilling gas flasks for surface-supplied diving operations or using the crane winch to deliver and recover surface-supplied divers from the water, divers tending on station were exposed to 83 dB (A) re 20µPa, which although considered safe exposure (NOEL) for 9.5 hours, resulted in topside divers not obtaining sufficient auditory rest. Off-duty divers using the workout area were subjected to even less off-duty auditory rest when considering other in-air and in-water noise exposures they may have encountered during a 24 hour period due to the noise level of 99.4 dB (A) re 20µPa (NOEL of 55 minutes) in that area. Using properly fitted insert, triple flange hearing protection, a diver's topside noise dose could potentially be reduced from 222% to 52% considering the range of noise levels shown in Table 2, and potentially be reduced to levels of 0% when using properly worn earmuffs that were in good working condition. This diving operation potentially resulted in high noise dose both in-water and in-air. A diver using the hydroblaster during a work-shift could receive a 58% in-water noise dose and a 52% in-air noise dose (if hearing protectors were worn) for a Total Noise Dose of 110%. This dataset is an example of high risk for hearing damage from both in-water and in-air exposure to the diver. The galley and bunkrooms were the two "safe auditory areas" onboard the barge where divers could obtain auditory-rest off-duty.

Table 2. In-air (topside) high-noise levels and sources on USS MONITOR salvage barge.

	Distance From Source (ft)	dB (A)
Hydroblaster Compressor	1	99.9
	5	99.7
	10	99.4
(Outside Gym Area)	15	97.4
Saturation Diving Launch & Recovery	5	99.0
Saturation Chamber Compressor	1	93.2
Morgan Crane Winch (Surface-supply dive station)	1	83.0
5000 psi Surface Supply Compressor	1	98.0
5000 psi Surface Supply Compressor (On surface supply dive station)	20	83.0

USS ARIZONA Memorial Hull Integrity Project

Mobile Diving and Salvage Unit One, Pearl Harbor, HI, and the National Park Service, Oahu, HI, were conducting a periodic hull integrity study of the USS ARIZONA Memorial in August of 2002. The ship still contains a substantial amount of oil within the hull so every five years three-inch diameter hull samples or "coupons" are obtained for metallurgical analysis to evaluate the integrity of portions of the ship's hull. These samples are taken from areas of the ship that are not adjacent to compartments containing oil. A non-Navy tested or non-ANU **magnetic hydraulic drill press** was used to extract coupons for this project. The drill press was powered by a hydraulic pressure unit (HPU) compressor located on the surface. The MK-21 diving rig with fins was used with the hydrophone cable married to the diver's umbilical and the hydrophone attached to the dive helmet handle (Figure 3). Air dives were made to depths ranging from 7 to 40 fsw. Diving operations were performed using a LCM craft (Figure 6) as the diving platform with the HPU located aft approximately 15 feet from dive station on the starboard side of the boathouse. The LCM was moored each day off either the bow or slightly forward of amidships of the USS ARIZONA.

Table 3 shows the in-water and in-helmet octave band, noise levels and the overall, power summed dB (A) in helmet-noise level using the magnetic hydraulic drill press. The overall 86.8 dB (A) re 20µPa in-helmet level resulted in an NOEL of 295 minutes (4 hours, 55 minutes) for the divers and combined with the observed daily exposure time of 135 minutes yielded a total in-water noise dose of 45.7%. In air exposure to the HPU for the operator 1-2 feet from the unit was 100 dB (A) re 20µPa for an NOEL of 30 minutes without using hearing protection and 97.8 dB (A) re 20µPa for an NOEL of 73 minutes using hearing protection. Total noise doses for these levels are 185% and 450%, respectively, without hearing protection. Using earmuffs and insert (double) hearing protection, with real-world attenuation (Berger, 1993) ranging from 25-30 dB, these noise doses are reduced to negligible levels. Using insert, plastic triple flange earplugs (mean real-world attenuation of 12-15 dB), noise dose could be reduced to 31-56% for the HPU operator and 23-38% for individuals on dive station, depending on the actual real-world attenuation achieved using earplugs. Taking these in-air noise doses and adding the 46% in-water noise dose a diver during this operation could potentially have a total noise dose ranging from 77 to 102% if a diver operated the HPU and completed a dive during a 24-hour period. Obviously exposure to the HPU on the surface presents a greater noise-exposure risk than the in-water exposure using the hydraulic drill press; however, having a total noise dose measurement showed that the combination of exposures would put the diver at risk for noise-induced hearing loss. The in-water measurements of the hydraulic drill press also served as another example of providing an on-site NOEL for non-Navy tested underwater tool.

Table 3. In-water, octave band noise measurements, dB (A) correction factors, dB (A) levels, MK-21 diving helmet attenuation correction factors, overall in-helmet dB (A) level, and NOEL for Magnetic Hydraulic Drill Press.

Hz	**31.5**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
dB re 1μPa	136.7	134.7	139.7	147.7	146.5	146.5	153.7	145.7	137.7
dB re 20μPa	110.7	108.7	113.7	121.7	123.7	123.7	127.7	119.7	111.7
dB (A) Correction Factors	-39.4	-26.2	-16.1	-8.6	-3.2	0	+1.2	+1.0	-1.1
dB (A)			97.6	113.1	120.5	123.7	128.9	120.7	110.6
MK-21 Mean Attenuation Correction Factors			-25	–34	-35	-52	-59	-62	-79
MK-21 In-helmet Levels			72.6	79.1	85.5	71.7	70.9	58.7	31.6
Overall In-helmet dB (A) Level	**86.8**								
NOEL	**295 minutes (4 hours, 55 minutes)**								

Underwater Construction

Noise measurements were obtained for several tools used in underwater construction and the results are displayed in Table 4. These data were obtained by working with two commands, the Navy Public Works Divers, Naval Station San Diego, and the Underwater Construction Training Team, Naval Diving and Salvage Training Center Panama City, FL in May 2003. Noise measurements were obtained for the **hydraulic hammer drill** (Stanley HD-45 with 1500-2000 psi input pressure) and a **hydraulic grinder** during dives to 40 fsw in San Diego Harbor. Noise measurements were also obtained for the same tools during dives to 20 fsw in Alligator Bayou at the Navy Diving and Salvage Training Center. All of these air dives were made using MK-21 rigs with either fins or boots with the hydrophone cable again married to the umbilical and the hydrophone attached to the helmet handle. Tables 4 and 5 display the data and NOELs for the hydraulic hammer and grinder, respectively. The data show that the NOEL for the hydraulic grinder, as for the hydraulic drill press discussed in the previous section, is substantially longer than the required time to complete the typical dive job using the tool. The hydraulic hammer drill has a substantially shorter NOEL; however, this permissible exposure time is also sufficient for the majority of dive jobs requiring use of this tool.

Table 4. In-water octave band noise measurements, dB (A) correction factors, dB (A) levels, MK-21 diving helmet attenuation correction factors, overall in-helmet dB (A) level, and NOEL for Hydraulic Hammer Drill.

Hz	125	250	500	1k	2k	4k	8k
dB re 1μPa	152.5	148.9	155.5	161.2	176.7	169.8	180.2
dB re 20μPa	126.5	122.9	129.5	135.2	150.7	143.8	154.2
dB (A) Correction Factors	-16.1	-8.6	-3.2	0	+1.2	+1.0	-1.1
dB (A)	110.4	114.3	126.3	135.2	151.9	144.8	153.1
MK-21 Mean Attenuation Correction Factors	-25	–34	-35	-52	-59	-62	-79
MK-21 In-helmet Levels	85.4	80.3	91.3	83.2	93.9	82.8	75.1
Overall In-helmet dB (A) Level	**96.7**						
NOEL		**89 minutes (1 hour, 29 minutes)**					

In-Water Noise Exposure for SCUBA Divers

In-water noise levels were also recorded for two diving operations using SCUBA, one involving NAVSEA testing of a non-ANU tool (air dives) in August 2003and the other involving NOAA and Navy research divers working at the Aquarius Undersea Habitat (air and Nitrox dives) in November 2003. As SCUBA divers are in an all-water environment with immersed ears, sound transmission to the inner ear is primarily by bone conduction (Adolfson & Berghage, 1974). Cudahy (2002) has developed a revised in-water standard for noise exposure for the frequency range of 500-8 kHz, with proposed NOELs given in dB SPL re 1μPa, since it is the typical in-water measurement reference. This standard involves measuring octave band noise levels for 500-8 kHz and weighting the sound pressure in each band to 500 Hz as the human ear in water is most sensitive at this frequency. It also takes into account in-water hearing threshold levels and in-air/in-water differences in dB SPL required to produce the same amount of temporary threshold hearing shift. The derivation procedure for acceptable eight-hour noise exposure limits is described in detail in Cudahy (2004).

Table 5. In-water octave band noise measurements, dB (A) correction factors, dB (A) levels, MK-21 diving helmet attenuation correction factors, overall in-helmet dB (A) level, and NOEL for Hydraulic Grinder.

Hz	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
dB re 1µPa	142.9	144.0	137.8	152.8	147.5	163.5	164.9
dB re 20µPa	116.9	118.0	111.8	126.8	121.5	137.5	138.9
dB (A) Correction Factors	-16.1	-8.6	-3.2	0	+1.2	+1.0	-1.1
dB (A)	97.6	113.1	120.5	123.7	128.9	120.7	110.6
MK-21 Mean Attenuation Correction Factors	-25	-34	-35	-52	-59	-62	-79
MK-21 In-helmet	72.6	79.1	85.5	71.7	70.9	58.7	31.6
Overall In-helmet dB (A) Level		**82.4**					
NOEL		**653 minutes (10 hours, 53 minutes)**					

The proposed in-water standard was applied to measurements performed by NAVSEA divers for a non-ANU approved **friction stud welder** tool. This tool is used to attach "patches" or metal plates involved in repair of ships and submarines. The NAVSEA dive team checked out one of NSMRL's portable USLM systems (Figure 1) and used a version of a "quick-setup" procedures manual for the system to perform the in-water noise measurements themselves. The tool was used and noise levels measured in the Navy Diving and Salvage Training Center dive tower. This structure was a concrete cylinder and represented a highly reverberant acoustic environment with resultant noise levels not being representative of open-water levels. It is assumed that in open water, noise levels would be less than those measured in the tower. Dives were made to a depth of 20 fsw. Octave band levels were power summed at 31.5-8 kHz and yielded an overall level of 154.4 dB. Using the in-water noise exposure derivation procedures yielded an NOEL of 8 hours (480 minutes), more than sufficient time to complete the majority of patch jobs. This NOEL is assumed very conservative considering the highly reverberant environment of the dive tower.

Measurements were also taken in water for the **diver audible recall system** for the Aquarius Undersea Habitat (Figure 6), the only undersea research laboratory currently in operation in the world. SCUBA divers work on and around the habitat at depths ranging from 50 to 130 fsw and at locations ranging from on the habitat itself to distances of up to 900 feet away. In-water noise guidance was again used to establish in-water NOELS. The recall system consisted of a Labell Labs L-1100 underwater projector or speaker that was mounted five feet above the center of the

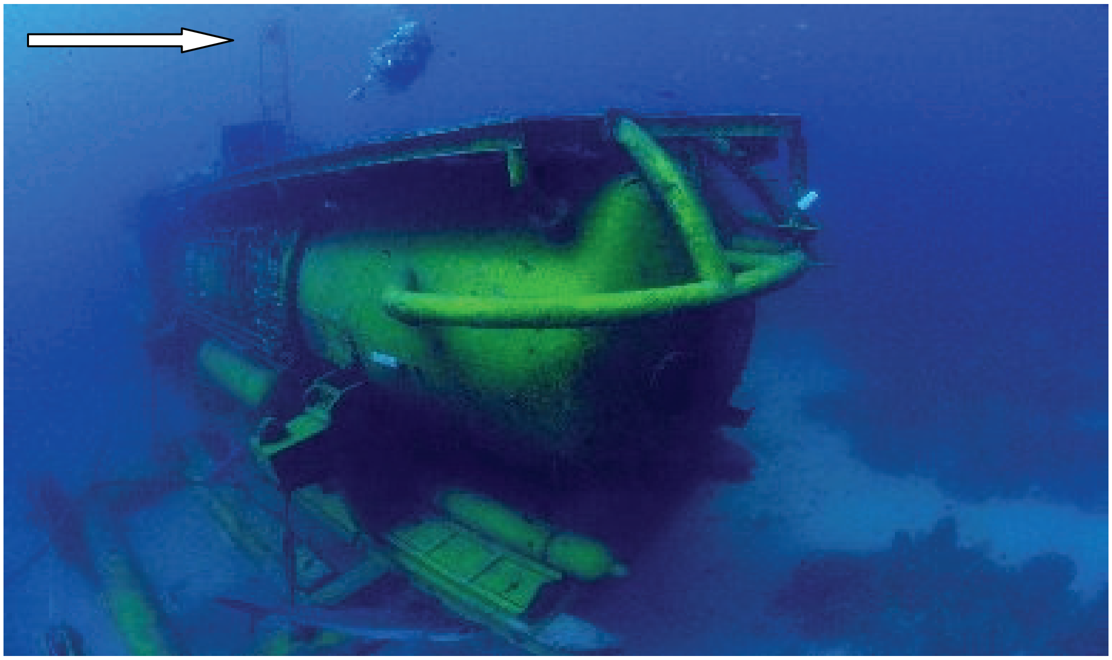

Figure 6. The NOAA/UNCW Aquarius Undersea Habitat as seen from the "bow" with the Labell Labs underwater projector used for the Diver Recall System indicated by the arrow. Photograph taken by Aquarius Technical Diver staff.

habitat and is seen in Figure 6 mounted into a steel frame just to the left of the SCUBA diver swimming above the habitat. The system is used to alert scientist and technical divers to return immediately to the habitat. The in-water overall SPL at 10 feet from the projector was 138.7 dB with an NOEL of 960 minutes, or 16 hours. Since the recall system is only used for 1-2 minutes, the in-water noise dose (1-2%) would be negligible. At the maximum range from the habitat for working dives (900 feet), the overall level was 113.2 dB, a level that exceeds in-water hearing thresholds sufficiently to be easily perceived by normal-hearing divers (Parvin & Nedwell, 1995; Al Masri et al., 1992).

In-air noise measurements were obtained in the Aquarius Life Support Buoy **diesel generator** and **compressor** spaces (Figure 7). With one generator and compressor in operation, dB (A) in-air noise levels were 105.6 and 94.6, re 20µPa, respectively. The NOELs, without the use of hearing protection were 11 minutes, 36 seconds for the diesel generator, and 1 hour and 27 minutes for the compressor. Aquarius support staff was required to use earmuffs while working for periods ranging from 15 minutes to one hour in the buoy. Without the use of hearing protection, in-air noise dose could range from 132-528% in the diesel generator room and from 17.2-69% in the compressor room depending on whether or not hearing protection was used and what type of protection was used. Using earmuffs (mean real-world attenuation of 20-25 dB) would increase NOELs to 14 hours and 41 minutes (881 minutes with 20 dB of attenuation) and to 6 hours and 72 minutes (432 minutes, with 25 dB of attenuation), respectively. Total in-air noise doses would vary from 3.5 to 13.8% for the diesel generator and to 1.7 to 6.8% depending on real ear attenuation provided by earmuffs for the compressor. As for the USS ARIZONA Memorial diving operation, the in-air noise exposures for these diving operations have more potential for exceeding daily noise dose if adequate hearing protection is not worn than does in-water noise exposure during diving. The use of double hearing protection would increase NOELs and decrease in-air noise doses even further. Total noise dose for divers (in water plus in air) for these diving operations could vary from 1.9 to 7% with use of earmuffs to 19.2 to 530% without the use of hearing protection.

Figure 7. Aquarius Life Support Buoy that provides life support (air, electricity) to the habitat (left). Diesel generators (right).

DISCUSSION

The goals of this applied research project were met. A valid and reliable procedure for measuring in-water noise levels for helmeted and SCUBA divers was established using portable, in-water sound measuring equipment that can be transported to almost any location in the world. During the course of this study, it was transported to locations as far away as Hawaii and eighteen miles off Cape Hatteras, North Carolina. Although the majority of the in-water noise measurements were performed at depths ranging from 7 to 40 fsw, several sets of data were successfully collected as part of the MONITOR project at a depth of 230 fsw. The same portable unit could be modified in two minutes or less to function as an in-air sound measuring system for which valid and reliable procedures have already been established (OPNAVINST 5100.23G, Chapter 18, 2005). This project differed from previous Navy studies in that in-water and in-air noise measurements were obtained during actual Navy and NOAA diving operations and in-water and in-air individual noise dosages were combined to obtain a Total Noise Dose for the diver during a 24-hour period. This represents a more valid estimate of potential hearing damage for the Navy diver, who appears to be at greater risk for noise-induced hearing loss than non-divers (Cudahy & Avila, 1998; Wolgemuth et al, 1995).

In addition, NSMRL provided in two instances, on-site in-water NOELs and noise dosages for Navy diving units in the field during diving operations that involved use of tools not currently approved for Navy use. These on-site NOELs derived for MK-21 divers was the result of using data both obtained by NSMRL and by NEDU (Knaflec, 1997; Russell & Cilento, 1995). NSMRL will continue to be available to perform such work, upon request, both to support Navy diving operations and to continue collecting data regarding noise levels produced by tools designed to be used underwater. In addition, this project demonstrated that valid and reliable in-water noise measurements can be obtained by Navy divers trained to operate the system. Appendix A is a *Quick Setup* Procedure Manual for using the B&K 2236 USLM system, developed by two of the authors and a U.S. Navy Master Diver. A quick setup procedures manual was critically important since the goal is to eventually have Navy divers performing the measurements and mitigation procedures necessary to implement an *in-water hearing-conservation program.* Appendix B is a comprehensive manual for using the more advanced B&K 2238 USLM system for obtaining occupational noise data for Navy divers. Appendix C is a data recording sheet that can be used to record either in-water or in-air noise measurement data. Information contained within this report and the appendices will be used to develop curriculum elements to be used as part of the diver-training program at the Navy's Diving and Salvage Training Center in Panama City, FL.

The portable USLM systems and Quick Setup Procedure Manuals are available to be checked out from NSMRL, Navy Dive Lockers can obtain noise measurements, and contact NSMRL to interpret the results and establish NOELS. This will also allow NSMRL to keep collecting results to add to the existing database so that a more comprehensive database will be available to NAVSEA, NEDU, and the Navy Environmental Health Center. Eventually, as curriculum elements are developed and as NSMRL completes research on in-water noise guidance, a procedures manual and guidance to compare noise measurements can be incorporated as an appendix in the U.S. Navy Diving Manual in the same way that Appendix 1-A (Safe Diving Distances from Transmitting Sonar) has been.

The most significant contribution of this study is the calculation of Diver Total Noise Dose. The U.S. Navy diver, like the commercial diver, is exposed to potential noise hazards both under the water and on the surface during diving support operations. Although the MK-21 or Kirby Superlite 17 diving helmet does provide attenuation (Russell, 1995) to sound transferring from the water to the in-helmet air environment, some tools (e.g., 20K hydroblaster) produce such high noise levels that exposure must be limited in time. On the surface, however, insert and circumaural hearing protection can be used, alone or in combination, and reduce the noise exposure and extend permissible exposure times substantially. During the course of this project, however, Navy divers working topside around compressors, generators, or other high noise sources were often observed to not use hearing protection. This phenomenon is not unique to the diving community, but clearly shows that challenges exist on the surface as well as in the water in the establishment of a comprehensive Navy diver hearing conservation program. While participating in the project, NSMRL scientist divers did recommend the use of hearing protection and typically, compliance was higher during the course of data collection. One dive locker that participated clearly had a strong hearing-conservation program in that the majority of their diver's topside used insert hearing protection consistently when the hydraulic power unit operating the hydraulic in-water tool was used. As with the surface and submarine fleets, and the Fleet Marine Force, hearing-conservation education and leadership involvement at all levels in enforcing and monitoring the use of hearing protection when appropriate is highly important. Total diver noise needs to be considered and monitored and steps need to be taken to mitigate the potential of noise-induced hearing loss in U.S. Navy divers. A product has been developed and successfully tested to provide the means to accomplish this important goal.

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APPENDIX A

Quick Setup B&K 2236 Underwater Sound Level Meter (USLM) System Operating Procedures

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After obtaining sound measurements, contact the NSMRL Diving and Environmental Simulation Department at either DSN 694-3391 (Dr. Ed Cudahy) or 694-4107 (Mr. Derek Schwaller) for assistance in interpreting the results. Commercial number is the same with (860) area code.

LOAD OUT LIST

1. Sound cable w/ hydrophone (2)
2. Sound level meter w/ sound cable adapter (2)
3. Hydrophone Calibrator
4. AA alkaline batteries for calibrator (12)
5. AA alkaline batteries for USLM (8)
6. Small shackle to be used as weight for hydrophone
7. Spool of line to use as strength member for hydrophone cable
8. Parachute cord
9. Data Recording Sheets
10. Calculator

The topside USLM system has several components and requires some assembly prior to use. The USLM system consists of a hand-held unit connected to a hydrophone on a 100-meter cable (a longer cable, i.e., 200-450 feet can also be provided). The hand-held unit collects and stores sound data. The hydrophone is the in-water sound sensor. The basic measurement procedure is to place the hydrophone at the underwater dive site, read the sound level on the hand-held unit, and write down the sound level on the data-recording sheet.

Figure 1 shows the case opened with the components packaged for shipping. There are three items shown in the Figure, the hydrophone in the small plastic case, the larger case in the upper right hand corner containing the USLM, a plastic bag containing the adapters, and the cable that connects the hydrophone to the USLM. The hydrophone is a B&K model 8104. The USLM is a B&K model 2236 or 2238 sound level meter.

Figure 1. The USLM system in carrying case. The normal placement of the USLM is in the opening of the cable coils in the right-hand section of the case. The white tags are depth markings.

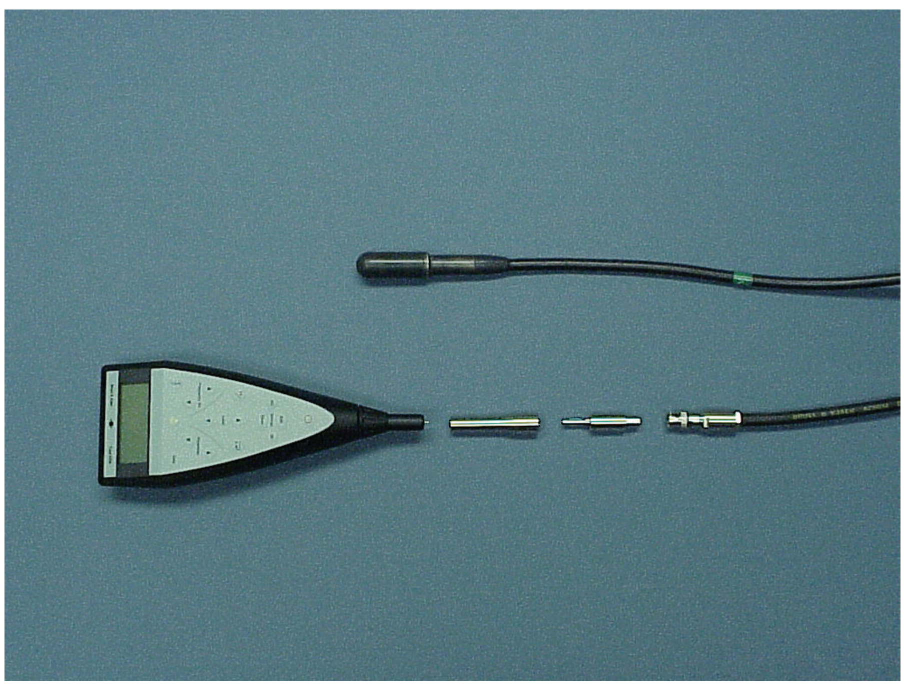

Figure 2. The USLM system unassembled with all the components shown. The components are laid out in the configuration in which they will be used for assembly. The user should familiarize them selves with each component prior to assembly. A cylindrically shaped calibrator for the USLM hand-held system is also enclosed (not shown).

ASSEMBLING THE UNDERWATER SOUND LEVEL METER (USLM) SYSTEM

1. Remove the components from the carrying case and confirm that all components shown in Figure 2 have been received.

2. Place the batteries into the B&K 2236 or 2238 USLM. They require 4 AA batteries. The orientation of each battery is shown on the inside of the battery compartment.

3. Check that the B&K 2236 or 2238 USLM display is **powered off.**

4. Take off (unscrew carefully) the microphone at the tip of the USLM and place in the plastic pill bottle container in the hand-held unit case. If you are uncertain of the location of the microphone refer to Figure 8.

5. Attach the **JJ2614 adapter** (shown in Fig 3) to the top of the B&K SLM. Screw the adapter on with only light finger torque.

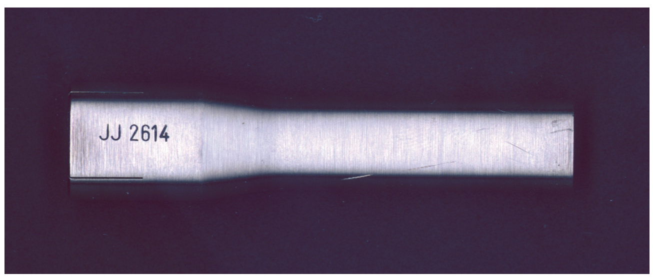

Figure 3. The JJ2614 adapter is shown. The narrow end on the right is attached to the USLM.

6. Attach the **JP0144 adapter** (shown in Fig 4) to the JJ2614 adapter by pushing the prong on the adapter into the socket of the adapter previously attached in step 4. Figure 5 shows the expected configuration at this point.

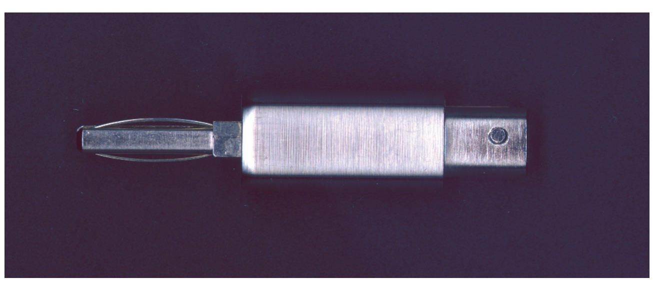

Figure 4. The JP0144 adapter is shown. The end on the left is inserted into the JJ2614 adapter.

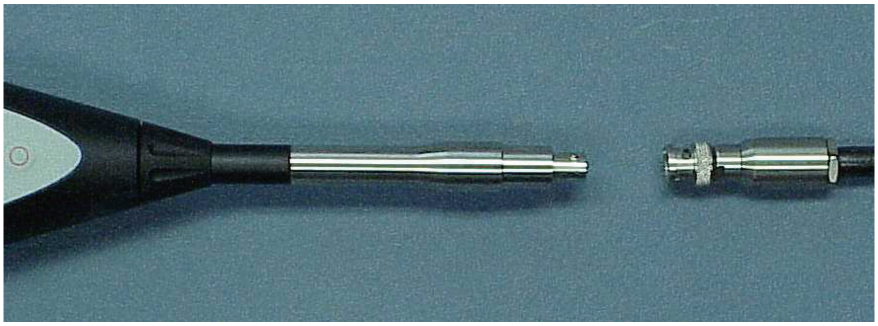

Figure 5. USLM System with adapters attached.

7. Connect the end of the hydrophone cable (male BNC connector) to the JP0144 adapter (female BNC connector) as shown in Figure 6.

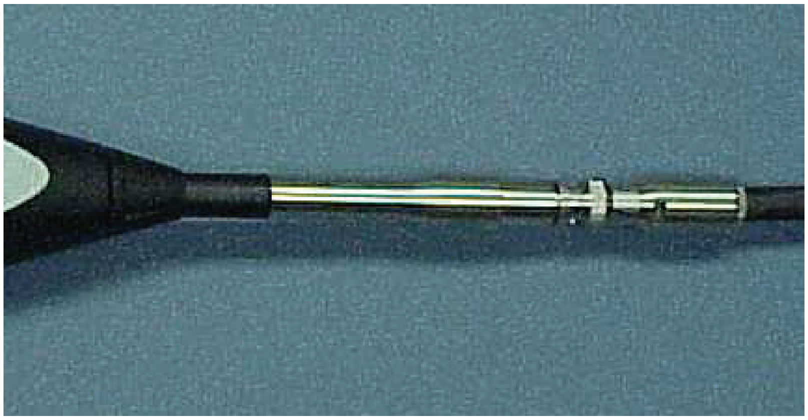

Figure 6. The connection between the USLM system with the two adapters and hydrophone cable is shown.

8. Use the velcro strap to provide strain relief for the adapter connections as shown in Figure 7. The USLM System is now fully assembled.

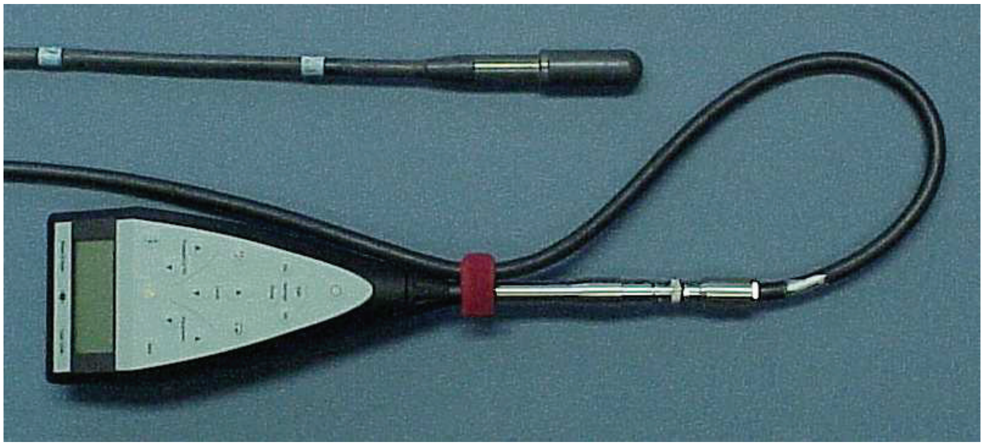

Figure 7. The USLM System showed fully assembled with strain relief for the cable.

9. Figure 8 shows a labeled picture of the display and function keys for the B&K 2236 USLM model. Refer to this figure when proceeding through the rest of the quick set up operating procedures.

Figure 8. Display and function keys for B&K 2236 Sound Level Meter.

Calibration procedure

1. Open the box containing the **B&K hydrophone calibrator** and remove the **4229 calibrator** and the **UA 0547 coupler**.

2. Check that the batteries are good using the battery test setting on the 4229. **Do NOT stay in the battery test mode** any longer than necessary to verify battery status. If left in this mode, the batteries will drain very quickly.

3. **Gently** screw the coupler onto the calibrator. The screw threads on the unit and adapter are very fine and can be easily stripped.

4. Insert the **B&K 8104 hydrophone** into the coupler.

5. Turn on the **calibrator** and the **B&K 2236 or 2238**.

6. Press the **Pause/Continue** button **[P]** and read the level indicated on the meter display. The level should read somewhere between 50 and 100 dB (L) or Linear. If display is not in this range go through the following steps:

   - Make sure the calibrator switch is ON, and not on Battery Test.

   - Push RESET [E] on the B&K 2236 or 2238 sound level meter and repeat the measurement.

   If the meter reads a level between 50 and 100 dB (L), the meter is ready to make measurements. Otherwise it must be returned to NSMRL for repair.

7. To apply a correction factor to perform in-water, sound level measurements, take the level observed on the display and SUBTRACT IT FROM 162.2. For example, if a field calibration level of 70 dB (L) is obtained subtract that from 162.2 (162.2 – 70 = 92.2 dB). The number 92.2 dB would then be added to any in-water sound levels measured to obtain the actual sound level in the water the diver is exposed to.

IN-WATER MEASUREMENTS: B&K 2236 USLM System

1. Press **Power** button on SLM (It will come on in “Pause” mode.)
2. Press **Frequency Wt. down arrow** button until dBL (Broad Band) shows up in the bottom RT portion of display screen.
3. Press **Level up arrow** button until the sound level range at the top of the display screen reads 60-140**.** If no sound level is displayed, push the **Level down arrow** button until a range is selected that displays a sound level.
4. Press the **Select Time Weighting** button at lower left of front panel until the lower left of display screen reads F SPL (Fast Sound Pressure Level)
5. Press **Pause/Continue** button and “PAUSE” will disappear from lower left of display screen. Now you are measuring sound.
6. Read dB L value in lower right of digital display and record on the data sheet (Appendix C) the highest sound level that is consistently seen over a 1 minute period.
7. Press **Pause/Continue** button again to stop measurement
8. Press **Frequency Wt. down arrow b**utton **again until** dBA (Human Hearing Frequency Band) shows up in the bottom RT portion of display screen.
9. Press **Pause/Continue** button again to resume sound level measurement.
10. Repeat Steps 5-7 for dBA value.
11. Press **Pause/Continue** button again to stop measurement.
12. Press **Frequency Wt. down arrow** button until 8 kHz is seen on digital display right above pause on left side of display.
13. Repeat Steps 5-7.
14. Press **Frequency Wt. down arrow** button until 4 kHz is seen, repeat Steps 5-7.
15. Press **Frequency Wt. down arrow** button until 2 kHz is seen, repeat Steps 5-7.
16. Press **Frequency Wt. down arrow** button until 1 kHz is seen, repeat Steps 5-7.
17. Press **Frequency Wt. down arrow** button until 500 Hz is seen, repeat Steps 5-7.
18. Press **Frequency Wt. down arrow** button until 250 Hz is seen, repeat Steps 5-7.
19. Press **Frequency Wt. down arrow** button until 125 Hz is seen, repeat Steps 5-7.
20. Press **Frequency Wt. down arrow** button until 63 Hz is seen, repeat Steps 5-7.
21. Press **Frequency Wt. down arrow** button until 31.5 Hz is seen, repeat Steps 5-7.
22. Press **Pause/Continue** button.
23. Press **Data** button TWICE and STORE overall results as record number….will be displayed.
24. Press **OK** to save in data record.
25. Call NSMRL (DSN: 694-3391/4107 or COMM 860-694-3391/4107) for assistance in interpreting results and setting a Noise Permissible Exposure Time.

IN-AIR MEASUREMENTS: B&K 2236 USLM System

1. Disconnect **BNC from USLM** and remove the **JP0144** and **JJ2614 adapters** from the **USLM.**
2. **CAREFULLY** re-thread the in-air microphone back onto the USLM.
3. Press **Frequency Wt. down arrow** button until dBL (Broad Band) shows up in the bottom RT portion of display screen.
4. Press **Level up arrow** button until the sound level range at the top of the display screen reads 30-110. If no sound level is displayed, press the **Level down arrow** button until a range is selected that displays a sound level. If OVERLOAD appears under the range scale at the top of the digital display, press the **Level up arrow** button to increase the range so that overload of the system does not occur.
5. Read dBL value in lower right of digital display and record on the data sheet (Appendix C) the highest sound level that is consistently seen over a one-minute period.
6. Press **Pause/Continue** button to stop measurement.
7. Press **Frequency Wt. down arrow** button until dBA shows up in the bottom RT portion of display screen.
8. Push **Pause/Continue** button again to resume sound measurement, read dBA value, and record on data sheet (Repeat Step 5).

Appendix B

Comprehensive User Guide for the B&K 2238 Top Side Underwater Sound Level Meter System

Derek Schwaller, B.S.E.

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USER GUIDE FOR THE B&K 2238 TOPSIDE UNDERWATER SOUND LEVEL METER System

I. Introduction

Navy divers are often exposed to high intensity underwater sound and guidance has been developed to address some of these noise exposures. An example of such guidance is Appendix A in the US Navy Diving Manual (Change 4, 2001). Recent developments in the miniaturization of sound measurement instrumentation and sensors has made possible the development of a portable underwater sound level meter that can be used by top-side personnel. This user guide provides instruction on how to set up and use the topside underwater sound level meter (USLM) system. The USLM system should be used with the appropriate guidance for monitoring permissible sound exposure for divers.

II. The B&K 2238 Topside Underwater Sound Level Meter System (USLM)

The topside USLM system has several components and requires some assembly prior to use. The USLM system consists of a hand-held unit connected to a hydrophone on a 100-meter cable. Longer cables are available to perform noise measurements for depths that exceed use of a 100-meter cable. The hand-held unit collects and stores data in addition to some analysis capability. The hydrophone serves as the in-water sound sensor. The basic measurement configuration is to place the hydrophone on the diver so that in-water noise levels at the underwater worksite can be read on the surface using the hand-held unit.

When shipped to the user, the components are packaged in a carrying case with a handle that can be used to transport the system wherever it is needed. The case has a combination lock. The combination will be provided to the user when the case is shipped. Figure 1 shows the case opened with the components packaged for shipping. There are three items shown in the figure, the **hydrophone** (small plastic case), a larger case containing the **hand-held noise measuring unit**, the **underwater cable** that connects the hydrophone to the hand-held unit, a plastic bag containing **adapters** to convert the hand-held from in-water to in-air noise measures, and a small plastic “pill bottle” container housing **the in-air microphone**. The hydrophone is a Bruel and Kjaer (B&K) model 8104. Figure 2 shows the components for the USLM system. The components are laid out in the configuration in which they will be used for assembly for in-water measurements.

Figure 1. The USLM system is shown in the carrying case used for shipping and transporting the USLM system to and from the work site. The hand-held unit case (upper right), protective case for the hydrophone (middle), hydrophone cable, and adapters (in bag at left) are shown in the case. The wooden case containing the in-air microphone is located inside the hand-held unit case. The normal placement of the hand-held unit case is in the opening of the cable coils in the right-hand section of the case. The white tags are depth markings for use in placing the hydrophone on-site in the water.

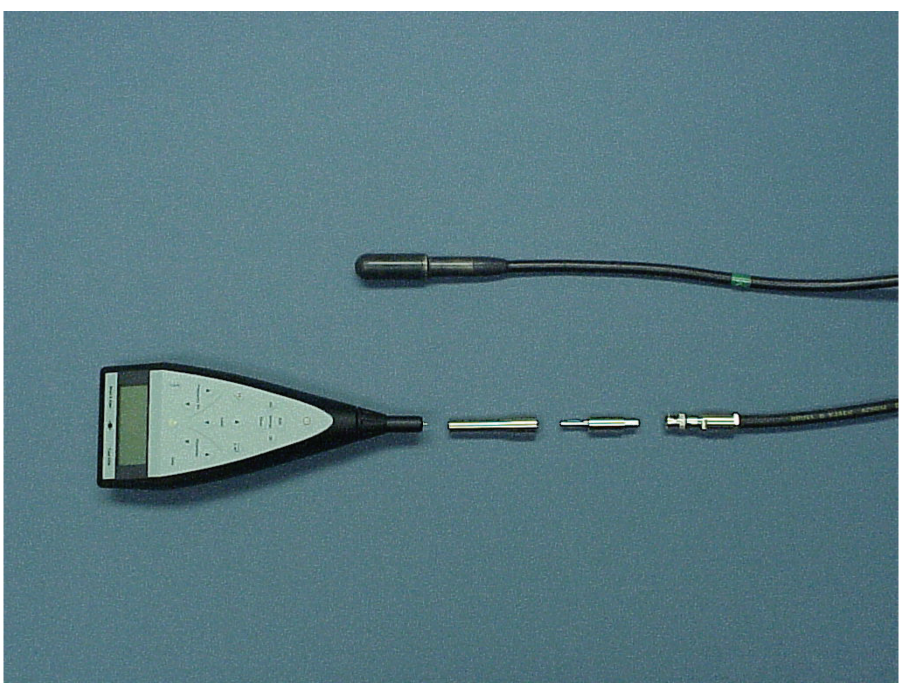

Figure 2. USLM system in-water components in order of assembly.

III. Assembling the Underwater Sound Level Meter

1. Remove the components from the carrying case and confirm that all components shown in Figure 2 have been received.

2. Place the batteries into the B&K 2238 sound level meter. It uses 4 AA batteries. The orientation of each battery is shown on the inside of the battery compartment.

3. Check that the B&K 2238 sound level meter display is off before continuing. An on/off switch is located at the top of the display section of the USLM.

Take off (unscrew carefully) the microphone at the tip of the B&K 2238 and place in the small plastic pill bottle container in the hand-held unit case. If you are uncertain of the location of the microphone refer to Figure 8.

4. Attach the JJ2614 adapter (shown in Fig 3) to the top of the B&K 2238 sound level meter Screw the adapter on using **light finger torque.**

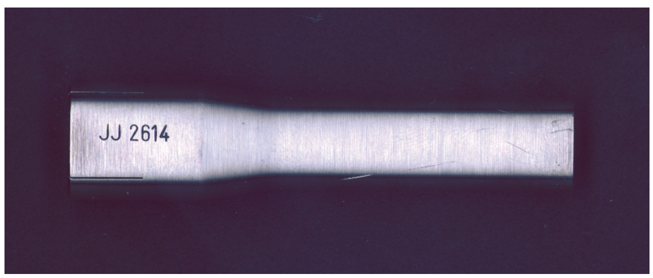

Figure 3. The JJ2614 adapter is shown. The narrow end on the right is attached to the B&K 2238.

5. Attach JP0144 adapter (shown in Fig 4) to the JJ2614 adapter by pushing the prong on the adapter into the socket of the adapter previously attached in step 4. Figure 5 shows the expected configuration at this point.

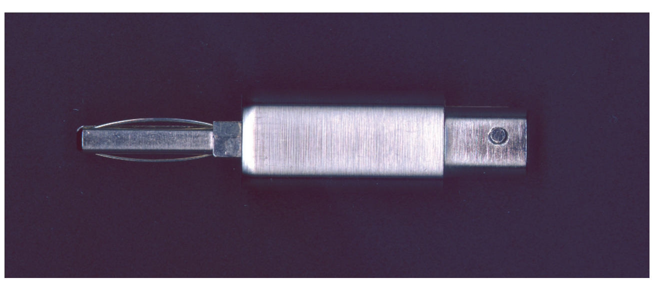

Figure 4. The JP0144 adapter is shown. The end on the left is inserted into the JJ2614 adapter.

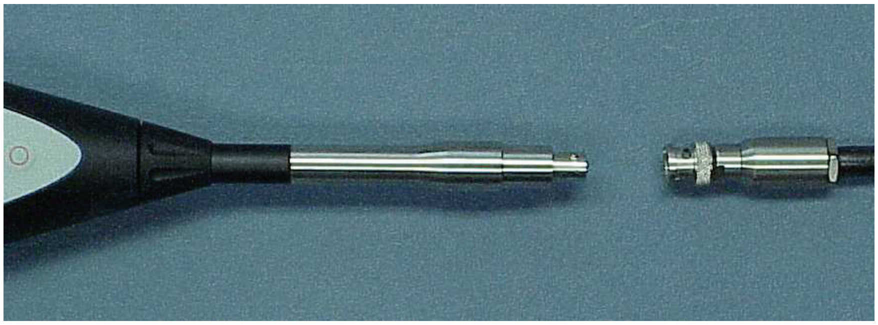

Figure 5. B&K 2238 system with adapter attached.

6. Connect the end of the B&K 8104 hydrophone cable (male BNC connector) to the JP0144 adapter (female BNC connector) as shown in Figure 6.

Figure 6. The connection between the B&K 2238 system with the two adapters and the hydrophone cable is shown.

7. Use the velcro strap to provide strain relief for the adapter connections as shown in Figure 7. The USLM system is now fully assembled **for in-water use**.

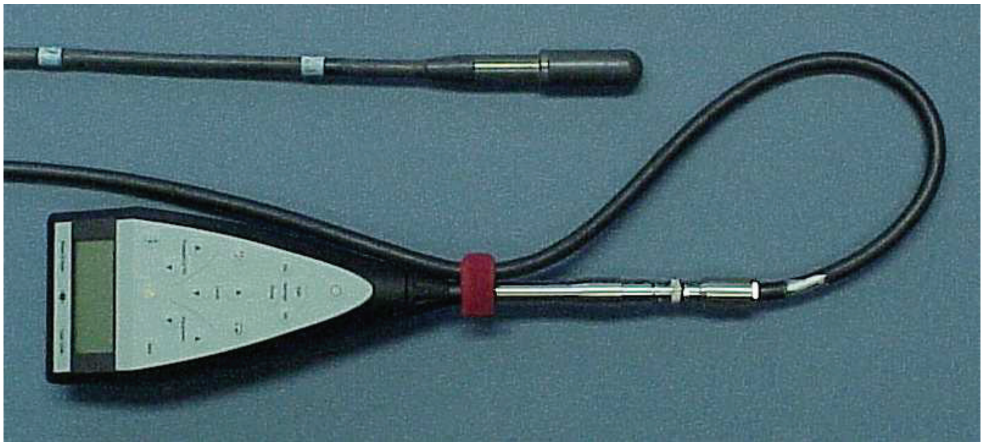

Figure 7. The USLM system showed fully assembled with strain relief for the cable.

IV. Checking the USLM Parameter Set

Figure 8 shows a labeled picture of the display and function keys for the B&K 2238 sound level meter. Refer to this figure when proceeding through the succeeding sections of the user guide.

The first step in using the USLM system is to make sure that the **correct test parameter set** is being used. This can be checked prior to assembling the USLM but can also be checked after assembly.

Figure 8. Display and function keys for B&K 2238 USLM

V. Verification of Operating Parameters for the USLM System

The USLM system will be calibrated prior to delivery, and must be recalibrated annually. Remember to use figure 8 for B&K 2238 control references.

1. Verify the **Frequency Weighting** (shown in the lower right hand corner of the display) **dBL** is the desired frequency weighting for the first test. If **dBL** is not shown on the display, press the **Frequency Wt.** (**right arrow** button) button until the **dBL** is displayed.

2. Verify the **measurement range setting**. The range indicator is displayed at the top of the display with the minimum possible level shown in the upper left corner and the maximum shown in the upper right corner. The range should be set at (20_100 dB). If this is not the case press the Level down ▼ button until the range is set to (20_100 dB).

NOTE: If the measurement range is set too low during your measurements, the signal will cause an **overload** on the sound level meter. If the USLM is overloaded, a **+ sign** is shown in the upper right corner of the display. In the example above this would be shown (20_100+), indicating a level exceeding 100 dB was measured. If this occurs press the **Level up (σ) [N]** button until the + disappears. This should only require pressing the level up button once or twice. **Failure to do so could damage the USLM system.**

3. Verify the **Time Weighting**. The time weightings available are shown below:

   F: (FAST) for frequently updated measurements of noise
   S: (SLOW) for checking average levels of fluctuating noise
   I: (Impulse) for measuring impulsive noise

   The time weighting is shown in the lower left corner of the display. To change the setting press the **FSI** button **[T]** on the lower left corner of the front panel. The setting for **in-water sound measurements** is **S.**

4. Once you have set all the settings correctly, press the **OK** button.
5. Perform **on site, field calibration** of the system:

   - Open the box containing the **B&K hydrophone calibrator** and remove the **4229 calibrator** and the **UA 0547 coupler**.

   - Check that the batteries are good using the battery test setting on the 4229. **Do NOT stay in the battery test mode** any longer than necessary to verify battery status. If left in this mode, the batteries will drain very quickly.

   - **Gently** screw the coupler onto the calibrator. The screw threads on the unit and adapter are very fine and can be easily stripped.

- Insert the **B&K 8104 hydrophone** into the coupler.

- Turn on the **calibrator** and the **B&K 2238 sound level meter component**.

6. Press the **Pause/Continue** button **[P]**and read the level indicated on the meter display. The level should read somewhere between 50 and 100 dB (L) or Linear. If display is not in this range go through the following steps:

    - Make sure the calibrator switch is ON, and not on Battery Test.

    - Check that the B&K 2238 switches correspond to the settings in section IV.

    - Press RESET [E] on the B&K 2238 and repeat the measurement.

    If the meter reads a level between 50 and 100 dB (L), the meter is ready to make measurements. Otherwise it must be returned to NSMRL for repair.

7. To apply an important correction factor to perform in-water, sound level measurements, take the level observed on the display and SUBTRACT IT FROM 162.2. For example, if a field calibration level of 70 dB (L) is obtained subtract that from 162.2 (162.2 – 70 = 92.2 dB). The number 92.2 dB would then be added to any in-water sound levels measured to obtain the actual sound level in the water the diver is exposed to.

8. The USLM system is now ready to take measurements.

VI. Making Measurements with the USLM:

In-water Measurements

Tool Noise: If possible, attach the hydrophone to the diver (For example, attach to the handle of the Mark 21 helmet, the top of the Mark 20 spider strap, or the SCUBA strap.) for most working dives, this would put the hydrophone one yard from the sound source. As much as possible, there should be a clear path between the sound source and the hydrophone on the diver **(Make sure that the hydrophone connection isn't stressed), however certain dive jobs may make this difficult. Obviously, the hydrophone should be attached so that it does not interfere with the work the diver is performing and should be attached in such a manner as to prevent damage to the hydrophone.**

1. Press **(**It will come on in "Pause" mode.)
2. Press
3. Use ▲ or ▼ in center of USLM to highlight Weightings on display screen of USLM
4. Push the OK Button soft key by pushing the on the LT side above the display screen,
5. In Weightings Window on display screen use the ▼ to highlight the Time Weighting Area.
6. Push ► until it reads F.
7. Next use ▲ to highlight the Broadband Wgt: area. If this does not read L for dB (L) then push the ► in center of USLM until L appears.
8. Use ▲ to Limits: area in Setup Menu. It should read 31.5-8 kHz. If it does not, then push the ▼ to highlight the number on the right.
9. Keep pushing the ► until the number on right is 8 kHz.
10. Next, push the ▲ to highlight number on the left.
11. Now push the ◄ until the number is 31.5 Hz.
12. Next push the ▲ to highlight Bandwidth: and hit the ► until it reads 1/1.
13. Press the Close Soft key on the RT side above the display screen.
14. You are now back in the Measurement Mode of the display screen. Hit the to begin measurement.
15. As the USLM system measures sound you will see reads in dB in the upper right of the display window and a graph below it that fills most of the display. Vertical bars will begin filling the graph on the right side and move left and the dB reading will fluctuate after each bar appears. Once these bars fill up the graph the dB reading will freeze. WRITE THE FINAL dB READING ON THE DATA SHEET.
16. Push .
17. Go back to the .
18. Select Weightings.

19. Scroll down to Broadband Wgt: Push ▶ until it says A.
20. Push OK soft key.
21. Push soft close key
22. Repeat steps 14-16.
23. Go back to .
24. Select Weightings.
25. Select Limits: Push ▼ so number on right is highlighted.
26. Push ◀ until the number on the right is equal to the number on the left (31.5 Hz).
27. Push OK soft key.
28. Push soft close key.
29. Push  and repeat steps 14-16.
30. Go back to Weightings Window and down to Limits:.
31. With left number highlighted Push ▶ to advance from 31.5 Hz to 63Hz.
32. Both numbers now should read 63 Hz.
33. Push OK soft key.
34. Push Select soft key.
35. Push  and repeat steps 14-16.
36. Repeat steps 30-32 to change numbers to 125 Hz.
37. Continue to carry out measurements until you have obtained and recorded sound levels up to the frequency band of 8 kHz following the steps above.
38. Go back to Weightings Window and down to Limits: one more time.
39. Highlight the ◀ until the Left Number is back down to 31.5 Hz.
40. **Storing the measurement** - Press the Data Files button twice. You should read **STORE Overall Results - as rec. no. 1 on the display.** To store the measurement press OK [E]. The measurement is now stored in the B&K 2238 memory as record #1. The following measurements will be stored as records 2, 3 and so on.

To perform and store another measurement repeat steps 1 through 4, as appropriate.

In-air Measurements

1. Disconnect BNC from the USLM and remove the JP0144 and JJ2614 **adapters** from the USLM.
2. **CAREFULLY** re-thread the in-air microphone back onto the USLM.
3. Follow procedures used for in-water measurements to record in-air measurements and record on data sheet.

Sound Level = Reading on USLM system + Correction Factor (Table 1) +

CALIBRATION CORRECTION FACTOR (Equation 1)

Refer to Table 1 for the correction factor associated with various placements of the hydrophone. This table assumes that the diver's head is approximately one yard from the sound source.

Table 1. Correction Factor Associated with Various Placements of the Hydrophone

Hydrophone/Diver Distance from Sound Source (yd)	Correction Factor (+)
1	0
2	6
3	9
4	12
5	14

<u>Sonar:</u> When measuring sonar in open water place the hydrophone at the anticipated diver location. Turn on the USLM by pressing the ⊕ button [C]. Adjust the Frequency Weighting by pressing the [R] key until 4KHz is shown in the lower right hand corner of the display [L]. Adjust the Time Weighting by pressing the [T] key until F is shown in the lower left corner of the display [L]. When the sonar turns on, press the Pause/resume key [P]. The USLM starts measuring with the selected set-up and the current dB SPL value is indicated on the display. Note the maximum value displayed. Calculate the sound value using equation 1 with a Correction factor of 0. Use this dB SPL value to apply the safe diving distance tables in the US Navy Diving Manual (Rev 4), Appendix A. If the sonar isn't listed in the tables, contact NAVSEA OOC at (703) 607-2766.

NOTE: If there is more than 1 minute of measurement results in the B&K 2238's buffer, the display tells you that the resetting will erase all previous measurement results from the buffer. If this occurs, press (**OK**) to confirm that you want to reset the B&K 2238. The B&K 2238 sound level meter is now reset and in pause mode.

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APPENDIX C

In-water/In-air Data Recording Sheet

Measured by: Time: Tool

Calibration level: dB(L)

Correction factor 162dB-Calibration level dB(A) Date:MM/DD/YY

31.5 HZ 63 HZ 125 HZ 250 HZ 500 HZ

1 KHZ 2 KHZ 4 KHZ 8 KHZ

comments:

Measured by: Time: Tool

Calibration level: dB(L)

Correction factor 162dB-Calibration level dB(A) Date:MM/DD/YY

31.5 HZ 63 HZ 125 HZ 250 HZ 500 HZ

1 KHZ 2 KHZ 4 KHZ 8 KHZ

comments:

Measured by: Time: Tool

Calibration level: dB(L)

Correction factor 162dB-Calibration level dB(A) Date:MM/DD/YY

31.5 HZ 63 HZ 125 HZ 250 HZ 500 HZ

1 KHZ 2 KHZ 4 KHZ 8 KHZ

comments:

Measured by: Time: Tool

Calibration level: dB(L)

Correction factor 162dB-Calibration level dB(A) Date:MM/DD/YY

31.5 HZ 63 HZ 125 HZ 250 HZ 500 HZ

1 KHZ 2 KHZ 4 KHZ 8 KHZ

comments: